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(71) Applicant: **MKS INSTRUMENTS, INC.**
Six Shattuck Road
Andover Massachusetts 01810(US)

(72) Inventor: **Ewing, James H.**
100 Simonds Road
Lexington, MA 02173(US)

(74) Representative: **Feldkamp, Rainer, Dipl.-Ing.**
Patentanwälte Wallach, Koch, Dr. Haibach, Feldkamp et al
P.O. Box 121120
W-8000 München 12 (DE)

(54) Liquid delivery and vaporization system.

(57) An improved vaporization system includes an automated valve and positive displacement pumping system using a pair of pumps operating in opposition to one another to provide continuous and constant volumetric flow at a constant predetermined pressure to an improved vaporizer using a stack of heated disks to flash vaporize the liquid. The valves are improved by providing one way flow.

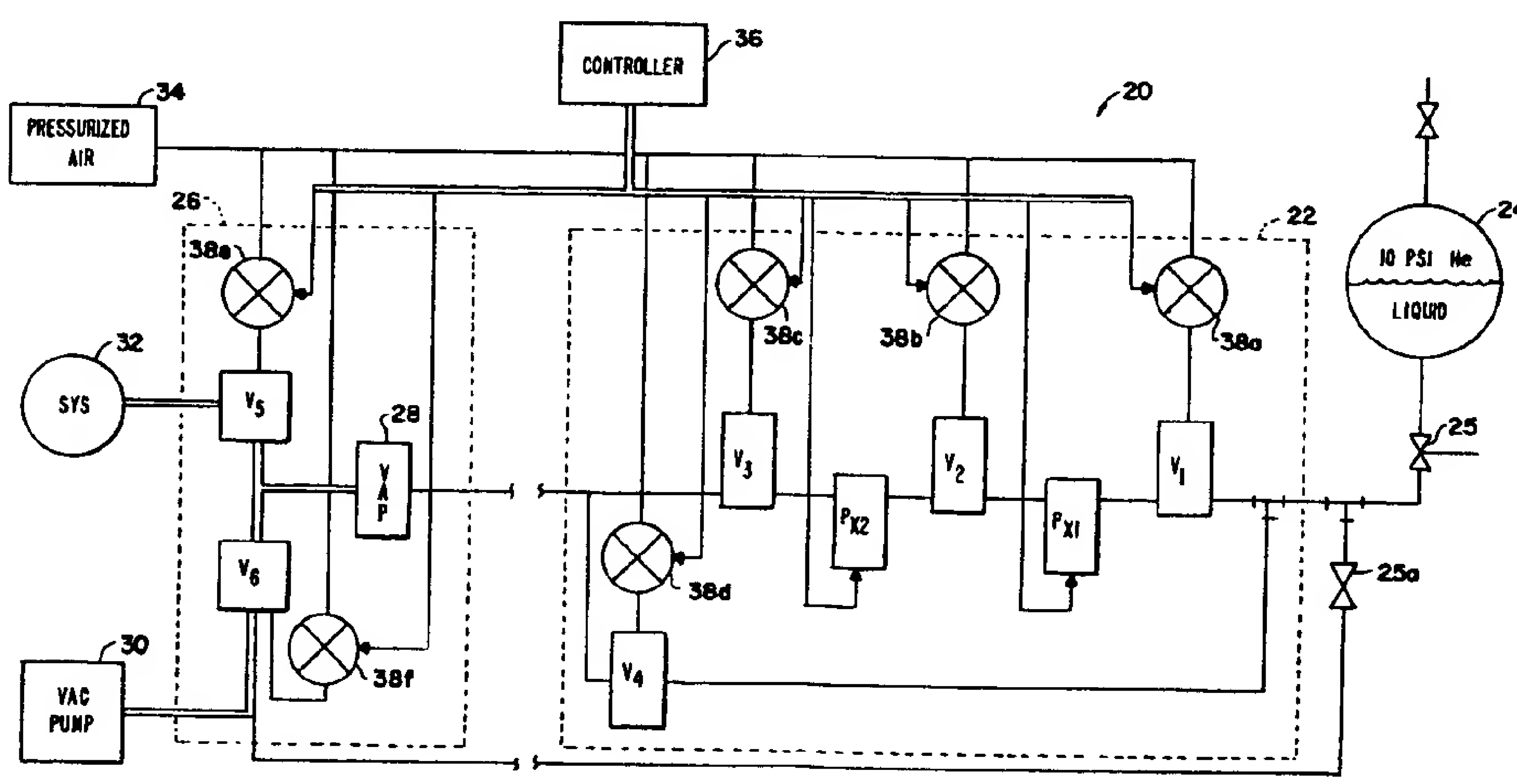

Fig. 1

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The present invention relates to liquid pumps and vaporizers, and more particularly to an improved liquid delivery and vaporization system including a novel positive displacement pump assembly for delivering a continuous volume flow at a constant rate to an improved vaporizer assembly for flash vaporizing the liquid.

Many processes are known where corrosive, sometimes pyrophoric, liquid materials must be vaporized so that the gas vapors can be subsequently used in carefully controlled amounts in a process chamber as a part of a carefully environmentally controlled process. Because of the toxic and dangerous nature of these materials, systems for delivering the liquids to the vaporizer, as well as the vaporizer itself, must be carefully sealed to prevent the escape of the materials. Various such systems are known. One type of system automatically fills the liquid into a bottle. The bottle is heated in order to increase the vapor pressure in the bottle up to a sufficient pressure so that a thermal mass or pressure based flow meter can be used to measure and control the flow of the gas. In some of these systems inert gas is also bubbled through the liquid in order to help carry off more vapor. Such systems tend to be relatively expensive and cumbersome, with vapor flow lines requiring extensive heating to prevent condensation.

It is a principal object of the present invention to provide an improved liquid delivery vaporization system which overcomes, or substantially reduces the problems of the above-noted prior art.

A more specific object of the present invention is to provide an improved relatively simple and inexpensive liquid delivery and vaporization system adapted to be mounted directly on the processing chamber requiring few, if any, vapor flow lines.

Another object of the present invention is to provide an improved vaporizer for vaporizing a liquid in an energy efficient manner, with minimal atomization, and without the need for additional inert gases.

And another object of the present invention is to provide an improved positive displacement pumping system for delivering liquid to a vaporizer at a continuous constant volumetric flow rate and subtantially independent of downstream pressure.

And yet another object of the present invention is to provide an improved pump assembly for pumping liquid at a continuous, constant volumetic rate with minimal parts exposed to the liquid passing through the pump.

And still another object of the present invention is to provide an improved valve for allowing flow to occur only in one direction when a threshold pressure at the inlet of the valve has been achieved.

In accordance with one aspect of the present invention these and other objects of the present invention are achieved by an improved vaporizer comprising a plurality of relatively thin disks supported in a stack and heated above the vaporization temperature of the liquid so that when liquid is forced between adjacent surfaces of the disks the liquid flash vaporizes with little atomization.

In accordance with another aspect of the present invention an improved valve system is provided. The valve system comprises means for biasing a valve body closed on a valve seat with sufficient force so that the valve will open in response to a predetermined pressure at its inlet, but will not open in response to the predetermined pressure when exerted as back pressure on the valve body while the valve system is closed. Means are also provided for independently exerting a force opposite the biasing force so that the valve can be opened.

In accordance with another aspect of the present invention an improved pump is provided. The pump pumps fluid at a continuous and constant volumetric rate. The pump comprises means for varying the volume of the pump chamber so that the pump can be filled and liquid subsequently delivered. The means for varying the volume of the pump chamber includes a compartment filled with a substantially incompressible fluid, such as oil. The compartment and chamber are separated by means for decreasing the volume of the chamber when the actuating means applies pressure to the incompressible liquid so as to provide positive pressure toward the outlet, and increasing the volume of the chamber when the actuating means withdraws pressure from the incompressible liquid so as to provide negative pressure relative to the inlet so as to fill the chamber.

Finally, in accordance with yet another aspect of the present invention an improved positive displacement pump assembly is provided for pumping fluid at a continuous, predetermined volumetric rate. The assembly includes control means for cyclically operating a first pumping means (shown and described in Fig. 1 as P_{x1}) connected between a first and second valve means (shown and described in Fig. 1 as V_1 and V_2, respectively) and second pumping means (shown and described in Fig. 1 as P_{x2}) connected between the second and a third valve means (shown and described in Fig. 1 as V_2 and V_3, respectively) as follows:

(a) with the first valve means (V_1) open and the second valve means (V_2) closed, operating the second pump means (P_{x2}) in its delivery phase so as to pump fluid in the chamber of the second pumping means (P_{x2}) through the third valve means (V_3), and operating the first pump means (P_{x1}) in its filling phase so as to fill the chamber of the first pumping means with fluid passing through the first valve means (V_1) at a

volumetric rate greater than the predetermined rate so that the chamber of the first pump means (P_{x1}) is filled prior to the completion of the delivery phase of the second pump means (P_{x2});

(b) closing the first valve means (V_1) while maintaining the second valve means (V_2) closed when the chamber of the first pump means (P_{x1}) is filled;

(c) commencing the first pump means (P_{x1}) in the delivery phase while maintaining the first and second valve means closed (V_1, V_2) so that when the fluid in the first pump means (P_{x1}) reaches a predetermined pressure (i) the second valve means (V_2) opens and the third valve means (V_3) remains open, (ii) the second pump means (P_{x2}) commences its filling phase, and (iii) the first pump means (P_{x1}) continues operating in its delivery phase so that the volume of fluid delivered from the chamber of the first pump means (P_{x1}) to the chamber of the second pump means (P_{x2}) while the latter is filling results in fluid passing though the third valve means (V_3) at the predetermined volumetric rate.

Other objects of the invention will in part be obvious and will in part appear hereinafter. The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the present invention, reference should be had to the following detailed description taken in connection with the accompanying drawings, wherein:

Fig. 1 is a schematic diagram generally illustating the preferred delivery and vaporization system of the present invention;

Fig. 2 is a schematic illustration taken in longitudinal cross section through the preferred embodiment of the pump as designed and used in accordance with the present invention;

Fig. 3 is a schematic illustration taken in longitudinal cross section through the preferred embodiment of each of the valves V_1 - V_4 of Fig. 1 as designed and used in accordance with the present invention;

Fig. 4 is a schematic illustration taken in longitudinal cross section through the preferred embodiment of the vaporizer as designed and used in accordance with the present invention;

Fig. 5 is a longitudinal cross sectional view of the preferred embodiment of the pump assembly shown generally in Fig. 1;

Fig. 6 is an enlarged more detailed longitudinal cross-sectional view, partially cut away, of the pump and valve shown in Fig. 5;

Fig. 7 is a longitudinal cross sectional view of the preferred embodiment of the vaporizer shown generally in Fig. 1; and

Fig. 8 is a flow chart illustrating the operation of the controller for sequencing the components of the vaporization system of the present invention.

In the drawings the same numbers are used to referred to the same or similar parts, and the same number with letters designating identical parts.

Referring to Fig. 1, the vaporization system of the present invention, generally shown at 20, comprises a pump assembly 22 having its inlet connected to a reservoir 24, the latter preferably being pressurized. The liquid provided by reservior 24 to the assembly 22 can be controlled with the valve 25 separately operated by the operator. Pump assembly 22 is a positive displacement pump adapted to continuously pump liquid at a constant volumetric rate. The pump assembly has a first valve V_1 having an inlet connected to receive liquid from the reservoir 24 and an outlet connected to the inlet of a first pump P_{x1}. The outlet of the pump P_{x1} is connected to the inlet of valve V_2, which in turn has its outlet connected to the inlet of pump P_{x2}. The latter has its outlet connected to the inlet of valve V_3. The outlet of valve V_3 forms the outlet of the pump assembly 22. A fourth valve V_4 has its inlet connected to the outlet of valve V_3 and its outlet connected to the inlet of valve V_1 and is used when the pump assembly operates in a recirculating mode. As will be described in greater detail hereinafter, the valves V_1, V_2, V_3 and V_4 are each designed as "one way" valves so that, if closed, they will not open in response to back pressure.

The system 20 also includes a vaporizer assembly 26 having a vaporizer 28, the latter having its inlet connected to the outlet of the pump assembly 22 (i.e., the outlet of the valve V_3) so as to receive the liquid output of the pump assembly. Valve 25a and its downstream piping are used for pump and vaporizer evacuation such that the entire system may be liquid-filled without trapped gases. As will be evident hereinafter the the vaporizer 28 has two outlets, one for connecting the vaporizer gas output to a first valve V_5 of the assembly 26, the valve in turn being connected to the vacuum pump 30. The output of pump 30 is preferably connected to a closed system (not shown) for capturing the output of the vacuum pump when the latter is used. The other outlet of vaporizer 28 is connected to a second valve V_6 of the assembly 26, the latter valve being connected to a system 32, such as a processing chamber (not shown).

As will be more evident hereinafter, the vaporization system includes a controller 34 for controlling the sequencing and operation of the pumps P_{x1} and P_{x2} and valves V_1 - V_6 of the pump assembly 22 and vaporizer assembly 26. The controller preferably includes a microprocessor preferably programmed so as to operate the pumps and valves in accordace with a predetermined and novel sequence, all of which will be more evident hereinafter. In addition the preferred valves V_1 -V_6 are pneumatically actuated and therefore are connected to a source 34 of pressurized air, each through a corresponding electromechanical valve 38. The opening and closing of the latter also is controlled by the controller 34. As will be more apparent hereinafter, the pumps P_{x1} and P_{x2} and the valves V_1 - V_4 are constructed in a novel manner.

The pumps P_{x1} and P_{x2} are substantially identical, except as noted below, with a simplified schematic longitudinal cross sectional view of one of the pumps being shown in Fig. 2. As shown in Fig. 2, the inlet 52 and outlet 54 of each pump P are connected to the associated valves, indicated at 56 and 58, respectively. The pump includes a pump chamber 60 having a volume which changes as the pump fills and delivers. The chamber in turn connects the inlet to the outlet so that when the valves 56 and 58 are opened, liquid will pass through inlet 52 into the chamber 60, and subsequently through outlet 54. The pump P also includes a compartment 62 separated from the chamber 60 by an expandable bellows seal 64. It should be evident that other expandable elements, such as a diaphragm or a bellowfram can be used in place of the seal 64. The compartment 62 is filled with a substantially incompressible liquid, e.g., oil. Actuating means, shown in the form of a ram shaft 66, is movable through the seal 68 into and out of the compartment 62. The shaft preferably has a uniform cross sectional area along its length so that as the shaft 66 moves into or out of the compartment at a uniform rate, the displaced oil will respectively cause the bellows seal to expand or contract at a uniform rate resulting in the volume within the chamber increasing or decreasing at a uniform rate.

More specifically, during the filing phase of each pump, the shaft 66 retracts from the compartment 62 (and therefore causes the bellows seal 64 to contract) at a uniform rate. During this phase the valve 56 is opened in order to allow liquid to pass through the inlet 52 into the compartment 62. The volume of the chamber 60 enlarges at a uniform rate as the ram shaft retracts. During the delivery phase of the pump, the shaft 66 is movable in the opposite direction (in an upward direction in Fig. 2) so that the shaft moves into the compartment (and therefore causes the bellows seal to expand). As will be more evident hereinafter, during the delivery phase, the valve 58 may be initially closed so that any back lash in the system can be accounted for and the pressure of the liquid in chamber 60 increased to a predetermined level, before valve 58 is automatically opened in response to the increasing pressure at the inlet. The cross-section of each of the inlets and outlets 52 and 54 are of a relatively small dimension (e.g., 1/32nd or 1/16th of an inch) for reasons which will be described in greater detail hereinafter.

The valves V_1 - V_4 are also indentical to one another, with a simplified cross sectional view of one of the valves V being shown in Fig. 3. Each valve V includes an inlet 72 to and outlet 74 from the valve passageway 76. Both the inlet and outlet are of a relatively small cross-sectional dimension, and in the preferred embodiment are merely extensions of the inlets and outlets 52 and 54 of the associated pump as best seen in Figs. 5 and 6 described hereinafter. A valve seat 78 is provided within the passageway 76 at the outlet 74. A valve body 80 is movable within the passageway relative to the valve seat between an opened position wherein the end of the valve body (shown as a spherical ball 82) is spaced from the valve seat 78, and a closed position when the body 80, and in particular the ball 82, is in contact and seals with the seat. Means for moving the valve body 80 (and spherical ball 82) between the opened and closed position includes a piston 84 including a piston head 86 in contact with the valve body 80, a shaft 88, mounted for axial movement toward and away from the valve seat 78, for moving the valve body toward the valve seat and a pneumatic actuator head 90 for axially moving the shaft. The actuator head is disposed within an air chamber 92 so that it can move in the same axial direction as the valve body 80 and shaft 88. Means, in the form of one or more compression springs 94, bias the actuator head 90, shaft 88, piston head 86 and valve body 80 into the closed position. A flexible bellows seal 96 separates the liquid in valve passageway 76 from the actuating portion of the valve assembly. The force provided by the compression spring 94 is sufficient to maintain the valve closed until the pressure of the liquid in the bellow seal 96 exceeds a predetermined pressure due to the forces exerted by the liquid side of the bellows seal in contact with the bottom of the piston head 86. In the preferred embodiment of the valve assembly, the valve assembly is designed to automatically open when the predetermined pressure of the liquid in the passageway 76 of the valve assembly reasches 250 psi, although this design threshold pressure can vary. Further, because of the relatively small cross-sectional dimension of the outlet

74, when the valve assembly is closed and the back pressure of the liquid in outlet 74 reasches the threshold level the force exerted on the ball 82 is insufficient to open the valve due to the much smaller area upon which force is applied (compared to the area of the bellows seal in contact with the bottom of the piston head 86). An air line 97 is connected to the air chamber 92. When pressurized air is introduced through air line 97 into the chamber 92, sufficient force is applied to the actuator head 90 so as to move the head 90 axially against the bias of the compression spring 94 moving the shaft 88 and valve body 80 away from the valve seat 78 to the opened position. The O-ring seal 98 maintains the air chamber 92 air tight. Finally, if necessary a compression spring 99 can be provided to insure that the body 80 unseats from the valve seat 78 when the valve is opened.

The simplified longitudinal cross sectional view of the vaporizer 28 is shown in Fig. 4. Vaporizer 28 includes a heater assembly 100 including a block 102 and heater elements inserted in the block 104 so as to form a heat source for the stack of disks 106. The disks are preferably flat and annular in shape and very thin and secured in the absence of liquid flow in contact with one another so that good heat conduction is provided from the block 102 through the disks 106 and the surface area of each of the disks can be heated above the flash point of the liquid being pumped into the vaporizer. The disks, for example, can have a diameter to thickness ratio of 1 inch: 0.001 inch, although the dimensions and ratio can vary. A center aperture is formed in the heater block and aligned with the center apertures of the disks so that a small tube 108 can be positioned through the block and disks. The tube 108 is provided with a plurality of apertures around its circumference adjacent the internal rim of the disks so that liquid (indicated as L in Fig. 4) forced through the tube will be forced between the disks 106. To bias the disks together, while insuring the passage of liquid between the disks, an anvil 110 is biased, with for example one or more compression springs 112, into contact with the stack so as to force the disks of the stack into contact with one another and the heater block. The disks 106, anvil 110, springs 112 and the portion of the tube 108 extending through the heater block into the disks are all contained within a vaporization chamber 114 having the vapor outlet 116. As liquid is forced through the tube 108, it will force the disks apart against the bias of springs 112 so that liquid will be forced between adjacent disks. The large confronting surface areas of the disks provide large hot surface areas which heat the relatively thin layers of liquid therebetween above the flash point so that the liquid is flash vaporized and passed as vapor out of the outlet 116.

A more detailed illustation of the pump assembly is shown in Figs. 5 and 6. Three blocks 130a, 130b and 130c respectively are provided for defining the inlets 72 and outlets 74 of the valves V_1, V_2 and V_3. Valve V_4 is secured to the bottom of the block 130c. The latter are respectively secured to the top of each block. The outlet 74 of valve V_1 forms the inlet 52 of the pump P_{x1}, while the outlet 74 of valve V_2 forms the inlet 52 of the pump P_{x2}. The blocks 130 are secured with gaskets 132 so that the outlet 54 of block 130b is connected to the inlet 72 of block 130a, and similarly outlet 54 of block 130a is connected to the inlet 72 of block 130c. The bottom of each of the blocks 130a and 130b is counterbored so as to form the space for chamber 60 and compartment 62.

The pumps P_{x1} and P_{x2} are respectively connected with any suitable means such as plates 136 and screws 134 to the bottom of the respective blocks 130a and 130b. The open end of bellows seal 64 is secured between the bottom of the respective block and plate so as to separate the oil chamber 62 from the liquid passageway 60. Each plate includes a center aperture which is counter bored so as to provide an annular shoulder for supporting the O-ring seal 68. Each plate 136 supports a housing 138, which in turn supports the pumping actuator mechanism.

Specifically, a stepping motor 140 drives a shaft 142 of ball nut assembly 144 through the coupler 146. A rotation to linear motion translating element 148 for supporting the ram shaft 66 is secured to the nut assembly and slidable on the anti-rotation shafts 150 so that rotation of the stepping motor causes the shaft 142 of the ball nut assembly 144 to rotate. This, in turn, causes the element 148 to slide on the shafts 150 so that the ram shaft 66 can be moved within the O-ring seal 68 in and out of the oil in the compartment 62 depending on the direction of rotation of the motor 140.

Thus, by causing the stepping motor 140 to rotate in one direction at a constant angular speed, the shaft 66 will move into the compartment at a constant linear speed. Similarly, by reversing the direction of the motor and rotating the shaft 142 of the nut assembly at a constant angular speed in the opposite direction, the shaft 66 will retract from the chamber at a constant linear speed. For reasons which will be more evident hereinafter, the ram shaft 66b of the pump P_{x1} has a cross sectional area twice that of the ram shaft 66a of the pump P_{x2} so that for a given angular speed at which the motors 140 are driven, the ram shafts are driven into the corresponding compartment 62 at the same linear speed resulting in the ram shaft 66b displacing twice the amount of liquid in the chamber 60 of the block 130b than the ram shaft

66a displaces in the chamber 60 of the block 130a. As shown the only portions of the pump assembly exposed to the toxic and dangerous liquid is the block 130, bellows seal 64 and gasket 132. As such these elements are made of a material non-reactive with the liquid passing through the pump. For example, for most applications, these parts can be made of a stainless steel, although other materials are also available.

The valves V_1 - V_4 are all identical, with the details of the preferred valve being shown best in Fig. 6. Each valve is secured to a block 130 and includes a main block element 160 having a center bore for receiving the piston shaft 88. The main block element 160 is provided on its bottom surface with a cylindrical extension 162 within which a counter bore receives the bellows seal 96 and spring 99 and is in fluid communication with the inlet 72 and outlet 74 so as to define the passageway 76. The extension 162 is adapted to mate with a dimple formed in the top of the corresponding body 130 so as to insure that the valve is properly seated. The valve body 80 and ball 82 are disposed within the bellows 80 and are movable up and down (as shown in Fig. 6) between an opened and closed position, while the compression spring 99 is disposed within the bellows seal so as to insure the valve body unseats from the valve seat when the valve is opened. The top of the main block element 160 is also counter bored to receive the O-ring seal 98, and further counterbored at 163 on the top of the element so that the counterbore and cover plate 164, secured over the counterbore 163, form the air chamber 92. The O-ring 98 is provided on an annular shoulder formed in the main block element, while wells are formed in the plate 164 for receiving a plurality of compression springs 94. An air inlet 97 is formed in the main block element 160 so that air is forced into the chamber 92 forcing the actuator head 90, in an upward direction as shown in Fig. 6. Again the parts of the valve exposed to the liquid, i.e., the valve body 80, ball 82, bellows seal 96 and main block element 160 are all made of a material non-reactive with the liquid passing through the valve.

Finally, the vaporizer assembly 26 is shown in greater detail in Fig. 7. As shown, cap 170 is secured over the heating block 102 with a sealing gasket 172 so as to cover the disks 106 and anvil 110. The heating block 102 is provided with two valve seats 174 for receiving the valve body of the corresponding valves V_5 and V_6. The valves V_5 and V_6 are pneumatic valves and move the respective valve bodies 176 into and out of contact with the respective seats 174.

The operation of the entire vaporization system 20 will now be described. As shown in Fig. 8 the controller operates the pumping system 22 in accordance with a predetermined sequencing so as to provide a constant volumetric rate of flow of liquid at the output of the pump assembly to the vaporizer 28. More specifically, in Fig. 8 during start up, as indicated at step 200 valves V_1, V_2, V_3, V_4, V_6 and 25a are initially opened so that air will be removed from the pumps, vaporizer and interconnecting lines. When the pressure has been reduced to substantially zero (e.g., <50 milliTorr) valves V_6 and 25a are closed and valve 25 is opened allowing liquid to flow from the reservoir filling all evacuated spaces right up to the vaporizer disks. Pumping and vaporizing can now begin.

The controller proceeds to step 202 at the beginning of its operational cycle and will shut off the valve V_6 by closing the valve 38f, the stepping motor 140 and the ram shaft 66 of the pump P_{x2} will be at the beginning of the delivery phase of that pump, so that the ram shaft is fully retracted from the oil chamber. The stepping motor 140 and ram shaft 66 of pump P_{x1} will be at the beginning of the filling phase of that pump, so that the ram shaft will be fully extended into the oil chamber. At step 202 valve V_3 remain opened, V_4 remains closed, while valve V_5 is now opened (by opening valve 38e) and valve V_6 is closed so that vapor from the vaporizer assembly 26 will be diverted to the system 32. In addition, at step 202, valve V_2 is closed. During each cycle the pumps operate in opposition to one another so that the pump P_{x2} now begins to deliver liquid at a constant volumetric rate through the valve V_3 which opens automatically when the liquid pressure generated by pump P_{x2} reaches the level to overcome the spring force on top of the air piston (in the preferred example, 250 psi). Simultaneously, the stepping motor of pump P_{x1} begins its filling phase by operating at twice the speed of the stepping motor 140 of pump P_{x2} during the latter's delivery phase so that the position of the ram shaft of pump P_{x1} is at its nominal starting position halfway through the delivery phase of pump P_{x2}. The ram shaft is allowed to retract slightly further (e.g., typically an extra fifteen steps of the stepping motor out of a total 800 steps taken during the complete delivery phase) and stops at step 204. The delivery phase of pump P_{x2} continues until just before the delivery phase of that pump ends (in the example given, with 15 steps of the motor 140 of the pump P_{x2} being left before completion of the delivery phase).

At step 206 valve V_1 is pneumatically closed by closing valve 38a, the motor 140 of pump P_{x1} reverses and that pump begins its delivery phase with the valve V_2 remaining closed until the ram shaft 66 reaches the nominal starting position (in the example given, for the first fifteen steps of the motor). This enables the pump P_{x1} to accommodate any mechanical backlash in the ball nut as-

sembly of the pump P_{x1} and to compress the oil and liquid, to the extent they are compressible, in the chamber and passageway of the pump. At this point the pressure in the inlet of valve V_2 will be at the threshold level 250 psi.

Thus, at step 208, upon completion of the delivery phase of pump P_{x2}, pump P_{x1} is now ready to deliver liquid at a constant volumetric rate and predetermined pressure. At step 208 valve V_2 opens automatically due to the pressure upstream caused by pump P_{x1}. Pump P_{x1} will continue its delivery phase with valve V_2 opening automatically, and pump P_{x2} will begin its filling phase. Because pump P_{x1} delivers twice the volumetric rate as pump P_{x2}, pump P_{x1} will deliver enough liquid to simultaneous fill pump P_{x2} and deliver liquid out of valve V_3 at the same volumetric rate as was delivered by pump P_{x2}.

Once pump P_{x1} has completed its delivery phase at step 210 of operation, the process repeats with valve V_1 opening, closing valve V_2 due to the sudden drop in pressure because V_1 was pneumatically opened. The pump P_{x2} begins its delivery phase and pump PX1 begins its filling phase at twice the speed of pump P_{x2}, all by repeating step 202 and then subsequently repeating steps 204 - 210.

It should be appreciated that as the liquid is pumped through the vaporizer 28 by the pumps P_{x1} and P_{x2}, the liquid is flash vaporized and forced by pressure through valve V_5 to the system 32.

As shown in Fig. 8 if it is desired to temporarily stop the process at the end of step 210, the pump assembly can be operated in a recirculation mode, simply by opening valve V_4 by opening valve 38d to allow the output flow of liquid from valve V_3 to flow back to the input of valve V_1.

During the operational mode and recirculation mode, the stepping motors 140 of the pumps operate continuously, first in one direction for the filling phase, and then in the other direction for the delivery phase, with the reversing of direction from one phase to the other occuring almost instantaneously.

The system 20 thus described provides an improved relatively simple and inexpensive vaporization system adapted to be mounted directly on the vapor processing chamber requiring few short vapor flow lines. The improved vaporizer 28 vaporizes liquid in an energy efficient manner with minimal atomization, and without the need for additional inert gases. The pumping assembly 22 provides and improved positive displacement pumping system for delivering liquid to a vaporizer at a constant volumetric rate. The pumps P_{x1} and P_{x2} each provide an improved pump for providing a constant volumetric rate and pressure delivery when operating in a delivery phase with minimal parts exposed to the liquid passing through the pump. Each valve V_1 - V_4 provides an improved valve for allowing flow to occur only when a threshold pressure at the inlet of the valve has been achieved and remaining closed when the threshold pressure is applied as back pressure to the valve when the valve is closed.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted in an illustrative and not in a limiting sense.

Claims

1. Apparatus for vaporizing a liquid into a gas, said apparatus comprising:
- a plurality of relatively thin disks (106);
- means (108) for supporting the disks (106) so as to form a stack with the disks disposed parallel to and in contact with each other;
- means (110,112) for biasing said disks (106) together so as to form a stack;
- means (100) for heating the disks (106) to a temperature above the vaporization temperature of the liquid; and
- means for forcing the heated liquid between the disks (106) so that the disks separate against said biasing means (110,112) and liquid is forced through and flash vaporized in the spaces between said disks (106).

2. Apparatus according to claim 1, wherein said means (108) for supporting said disks includes liquid passage means for carrying said liquid under pressure to said disks (106).

3. Apparatus according to claim 2, wherein said means for carrying said liquid under pressure includes a hollow tube (108) disposed through the center of each disk (106), the tube including aperture means disposed so that liquid carried in said tube (108) under pressure is forced through said aperture and forces said disks (106) apart so that the liquid is heated and vaporized in the spaces between the disks (106).

4. Apparatus according to claim 1, wherein said means for biasing the disks includes an anvil (110), and means (112) for biasing said anvil (110) into contact with one end of the stack.

5. Apparatus according to claim 4, wherein said means (100) for heating said disks (106) in-

cludes heater means (102,104) for heating said disks (106), and said means (110,112) for biasing the disks (106) biases the other end of the stack into thermal contact with said heater means (102,104).

6. Apparatus according to claim 5, wherein said means for carrying said liquid under pressure includes a hollow tube (108) disposed through the center of each disk (106) and said heater means (102,104), the tube (108) including aperture means disposed so that liquid carried in said tube (108) under pressure is forced through said heater means and said aperture means into said spaces.

7. A valve system adapted to open in response to fluid at its inlet at a predetermined pressure and to stay closed in response to back pressure equal to said predetermined pressure exerted by the fluid at its outlet, said system comprising:
   - means for defining a closed passageway (76);
   - means for defining an inlet (74) to said passageway (76) for receiving fluid up to said predetermined pressure;
   - means for defining a fluid outlet (76) from said passageway (76) through which fluid passes out of said valve system;
   - means for defining a valve seat (78) within said passageway (76);
   - a valve body (80) movable relative to said valve seat (78) between an opened position wherein the body (80) is spaced from the seat (78) when the valve system is opened and a closed position wherein the body (80) is in contact with the seat (78) when the valve system is closed;
   - biasing means (94) for biasing said valve body (80) into said closed position, wherein the force created by said biasing means (94) on said valve body (80) is such that the force created by said fluid at said predetermined pressure at said inlet (72) causes said valve body (80) to move to the open position when said valve body (80) is in the closed position, while said valve body (80) remains in the closed position when said fluid at said predetermined pressure is provided at said outlet (74) when the valve body (80) is in the closed position.

8. A valve system according to claim 7, further including:
   - means (90,92,97) for providing a force on said valve body (80) greater than and in the opposite direction from the force provided by the biasing means (94) so that said valve body (80) can be quickly moved from the closed position to the opened position so that fluid is immediately provided at the outlet.

9. A valve system according to claim 8, wherein said means (90,92,97) for providing the force on said valve body (80) includes a piston (90) coupled to the valve body (80), said biasing means includes at least one compression spring (94) for biasing said piston (90) against said valve body (80) so as to bias said valve body in said closed position, and means (92,97) for receiving an actuating fluid for moving said piston (90) against said bias so as to move said valve body (80) to said opened position.

10. A valve system according to claim 9, wherein said actuating fluid is pressurized air.

11. A valve system according to claim 10, further including means (96) for sealing said passageway (76) from said piston.

12. A valve system according to claim 11, wherein said means for sealing includes a bellows seal (96).

13. A pump for pumping fluid at a constant output pressure, said system comprising:
   - means for defining a closed passageway (60);
   - means for defining a fluid inlet (52) to said passageway (60) for receiving fluid;
   - means for defining a fluid outlet (54) from said passageway (60) through which fluid passes out of said pump;
   - means for defining a compartment (62) for containing a substantially incompressible liquid;
   - actuating means (66) for applying and withdrawing pressure to said incompressible liquid;
   - wherein the compartment (62) and passageway (60) are separated by means (64) for decreasing the volume of said passageway (60) when said actuating means (66) applies pressure to said incompressible liquid so as to provide positive pressure toward said outlet (54), and increasing the volume of said passageway (60) when said actuating means (66) withdraws pressure from said incompressible liquid so as to provide negative pressure relative to said inlet (52) so as

to fill said passageway (60).

14. A pump according to claim 13, wherein said means for decreasing and increasing the volume of said passageway includes an expandable bellows seal (64) separating said passageway (60) from said compartment (62).

15. A pump according to claim 14, wherein said actuating means includes a shaft (66) having a uniform cross section along its length, and means (140) for moving said shaft (66) at a constant speed into and out of said compartment (62).

16. A pump according to claim 15, wherein said actuating means further includes a stepping motor (140) for moving said shaft at a constant speed into and out of said compartment (62).

17. A pump according to claim 16, wherein said actuating means includes a ball nut assembly (148) coupling said stepper motor (140) to said shaft (66).

18. A positive displacement pump assembly for pumping fluid at a uniform volumetric rate and constant pressure, said assembly comprising:
   - first pumping means (PX1), including a first chamber and reciprocally operable between delivery and filing phases, for delivering a first predetermined volume of said fluid at a predetermined rate;
   - second pumping means (PX2), including a second chamber and reciprocally operable between delivery and filling phases, for delivering a second predetermined volume of said fluid at the predetermined rate, wherein said first predetermined volume is greater than said second predetermined volume by a whole number factor;
   - first valve means (V1) for controlling the fluid provided to said first pumping means (PX1) when said first pumping means is operated in its filling phase;
   - second valve means (V2) for controlling the fluid delivered by said first pumping means (PX1) to said second pumping means (PX2) during the delivery phase of said first pumping means (PX1) and the filling phase of said second pumping means (PX2);
   - third valve means (V3) for controlling the fluid delivered by said second pumping means (PX2) out of said assembly during the delivery phase of said second pumping means (PX2); and
   - control means (36) for cyclically operating said first and second pumping means (PX1,PX2) and said first, second and third valve means (V1,V2,V3) as follows:

   (a) with the first valve means (V1) open and the second valve means (V2) closed, operating the second pumping means (PX2) in its delivery phase so as to pump fluid in the chamber of the second pumping means (PX2) through the third valve means (V3), and operating the first pumping means (PX1) in its filling phase so as to fill the chamber of the first pumping means (PX1) with fluid passing through the first valve means (V1) at a volumetric rate greater than the predetermined rate so that the chamber of the first pumping means (PX1) is filled prior to the completion of the delivery phase of the second pump means (PX2);

   (b) closing the first valve means (V1) while maintaining the second valve means (V2) closed when the chamber of the first pumping means (PX1) is filled;

   (c) commencing the first pumping means (PX1) in the delivery phase while maintaining the first and second valve means (V1,V2) closed so that when the fluid in the first pumping means (PX1) reaches a predetermined pressure (i) the second valve means (V2) opens and the third valve means (V3) remains open, (ii) the second pumping means (PX2) commences its filling phase, and (iii) the first pumping means (PX1) continues operating in its delivery phase so that the volume of fluid delivered from the chamber of the first pumping means (PX1) to the chamber of the second pumping means (PX2) while the latter is filing results in fluid passing though the third valve means (V3) at the predetermined volumetric rate.

19. A positive displacement pump assembly according to claim 18, wherein the filing phase of said first pumping means (PX1) allows for a predetermined amount of excess fluid to be provided to the first pumping means (PX1) so as to allow for compressibility of said fluid.

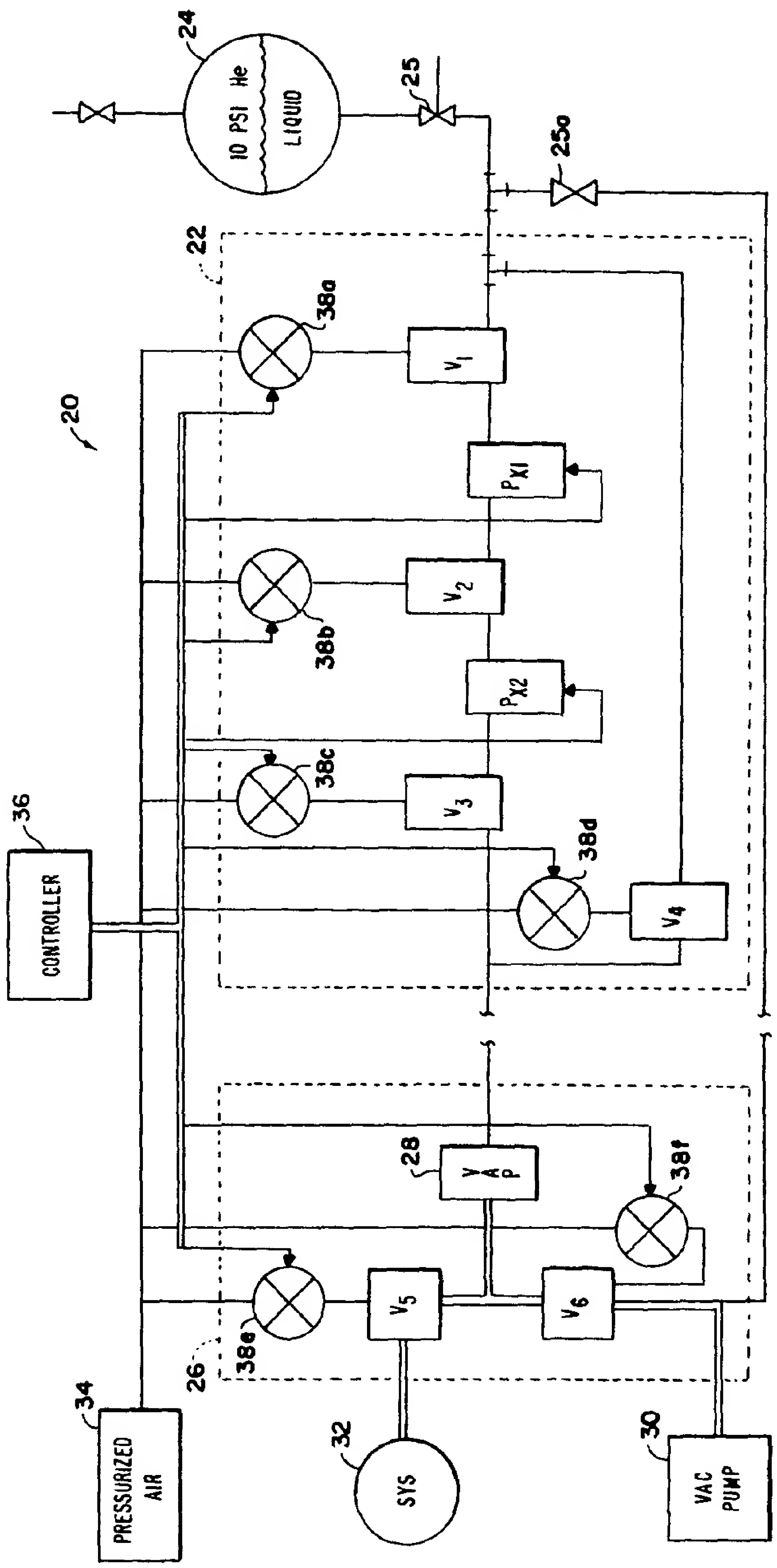
20. A positive displacement pump assembly according to claim 18, further including means for defining a relatively small sized passageway between said first valve means (V1) and said first pumping means (PX1), said first pumping means (PX1) and said second valve means (V2), said second valve means (V2) and said second pumping means (PX2), and said second pumping means (PX2) and said third

valve means (V3).

21. A positive displacement pump assembly according to claim 18, wherein the first predetermined volume is twice said second predetermined volume.

22. Apparatus for vaporizing a liquid into a gas, said apparatus comprising in combination:
- a vaporizer (26) for vaporizing said liquid;
- a positive displacement pump assembly (22), coupled to said vaporizer (26), for delivering liquid to said vaporizer at a continuous and constant volumetric rate and pressure, said assembly comprising:
- first pumping means (PX1), including a first chamber and reciprocally operable between delivery and filling phases, for delivering a first predetermined volume of said liquid at a predetermined rate;
- second pumping means (PX2), including a second chamber and reciprocally operable between delivery and filling phases, for delivering a second predetermined volume of said liquid at the predetermined rate, wherein said first predetermined volume is greater than said second predetermined volume by a whole number factor;
- first valve (V1) means for controlling the liquid provided to said first pumping means (PX1) when said first pumping means is operated in its filing phase;
- second valve means (V2) for controlling the liquid delivered by said first pumping means (PX1) to said second pumping means during the delivery phase of said first pumping means (PX1) and the filling phase of said second pumping means (PX2);
- third valve means (V3) for controlling the liquid delivered by said second pumping means (PX2) out of said assembly during the delivery phase of said second pumping means (PX2); and
- control means (36) for cyclically operating said first and second pumping means (PX1,PX2) and said first, second and third valve means (V1,V2,V3) as follows:

(a) with the first valve means (V1) open and the second valve means (V2) closed, operating the second pumping means (PX2) in its delivery phase so as to pump fluid in the chamber of the second pumping means (PX2) through the third valve means (V3), and operating the first pumping means (PX1) in its filling phase so as to fill the chamber of the first pumping means (PX1) with fluid passing through the first valve means (V1) at a volumetric rate greater than the predetermined rate so that the chamber of the first pump means (PX1) is filled prior to the completion of the delivery phase of the second pump means (PX2);
(b) closing the first valve means (V1) while maintaining the second valve means (V2) closed when the chamber of the first pumping means (PX1) is filled;
(c) commencing the first pumping means (PX1) in the delivery phase while maintaining the first and second valve means (V1,V2) closed so that when the fluid in the first pumping means (PX1) reaches a predetermined pressure (i) the second valve means (V2) opens and the third valve means (V3) remains open, (ii) the second pumping means (PX2) commences its filling phase, and (iii) the first pumping means (PX1) continues operating in its delivery phase so that the volume of fluid delivered from the chamber of the first pumping means (PX1) to the chamber of the second pumping means (PX2) while the latter is filling results in fluid passing though the third valve means (V3) at the predetermined volumetric rate.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LIQUID
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22
20
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V_1
P_{X1}
38b
V_2
P_{X2}
38c
V_3
38d
V_4
36
CONTROLLER
28
VAP
38f
38e
V_5
V_6
26
34
PRESSURIZED AIR
32
SYS
30
VAC PUMP

Fig. 1

Fig. 2

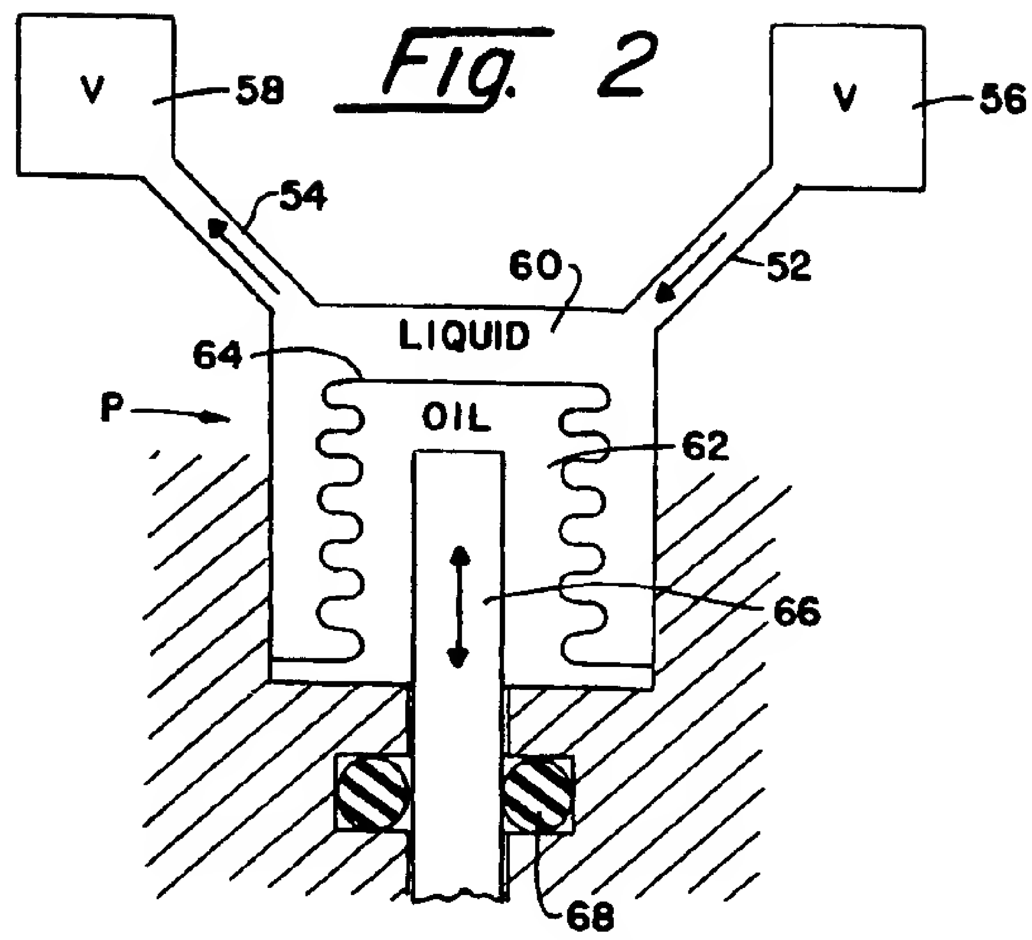


Fig. 3

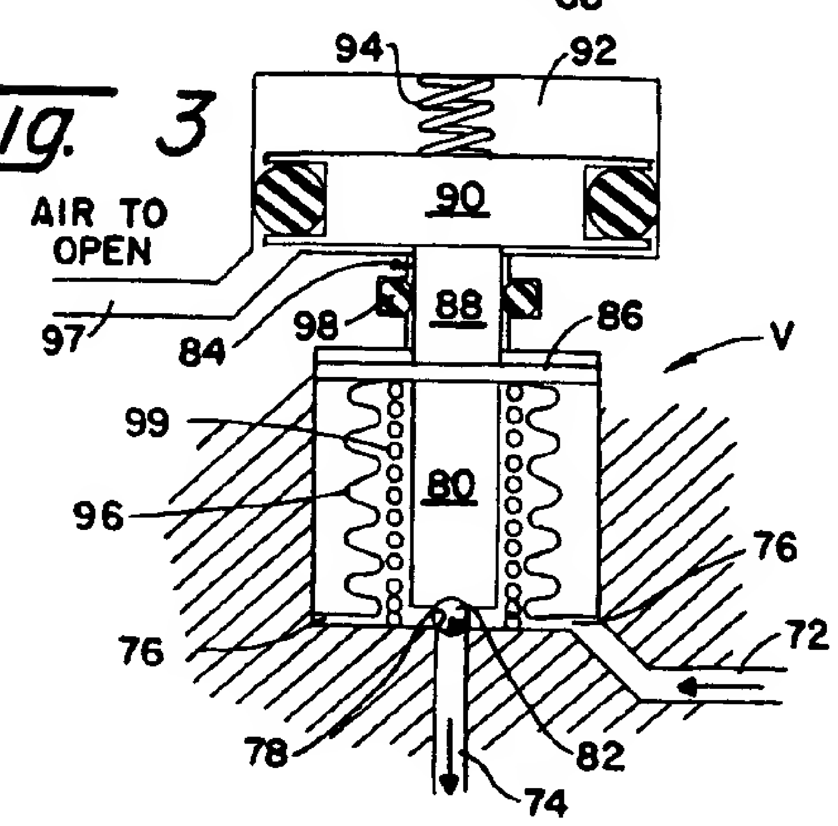
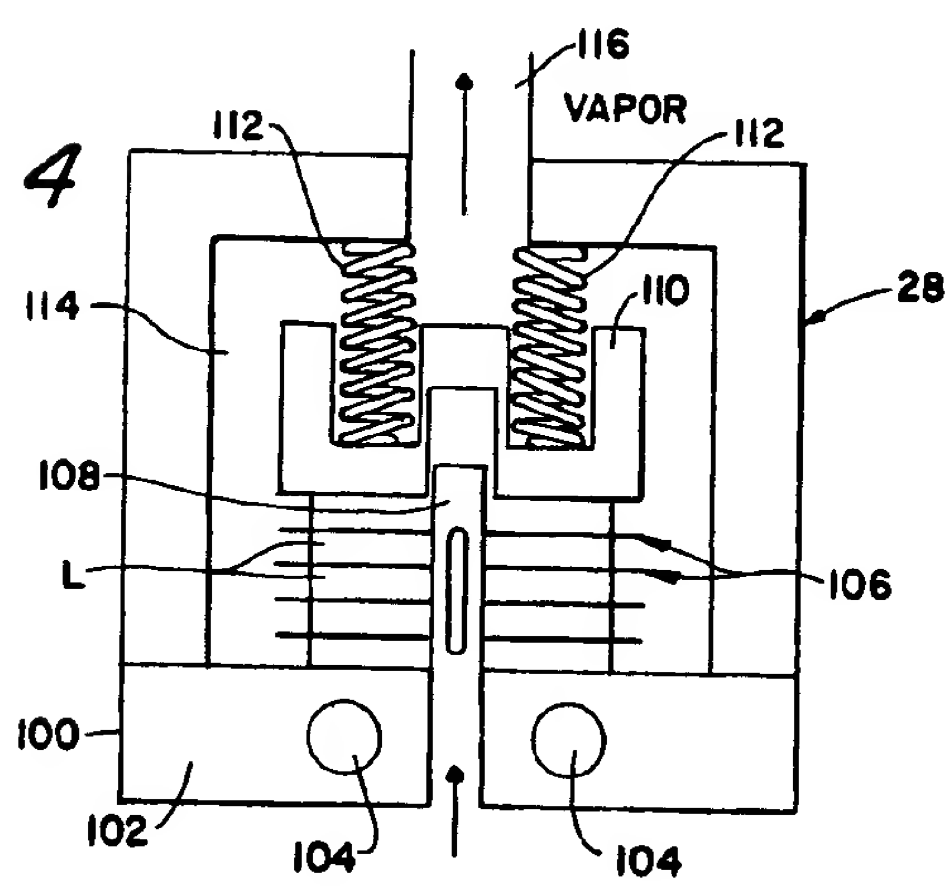
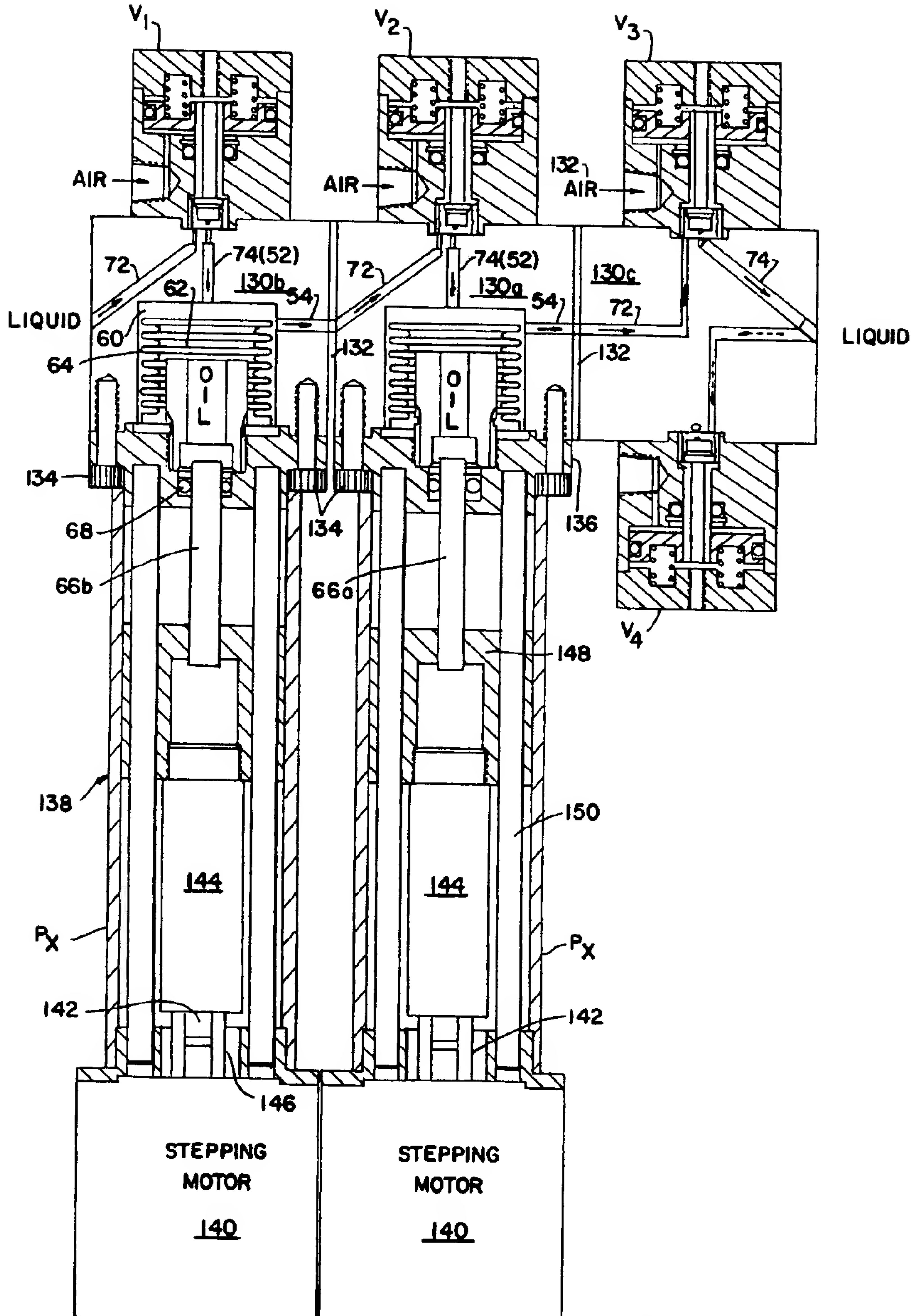


Fig. 4

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V2
V3
V4
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AIR
AIR
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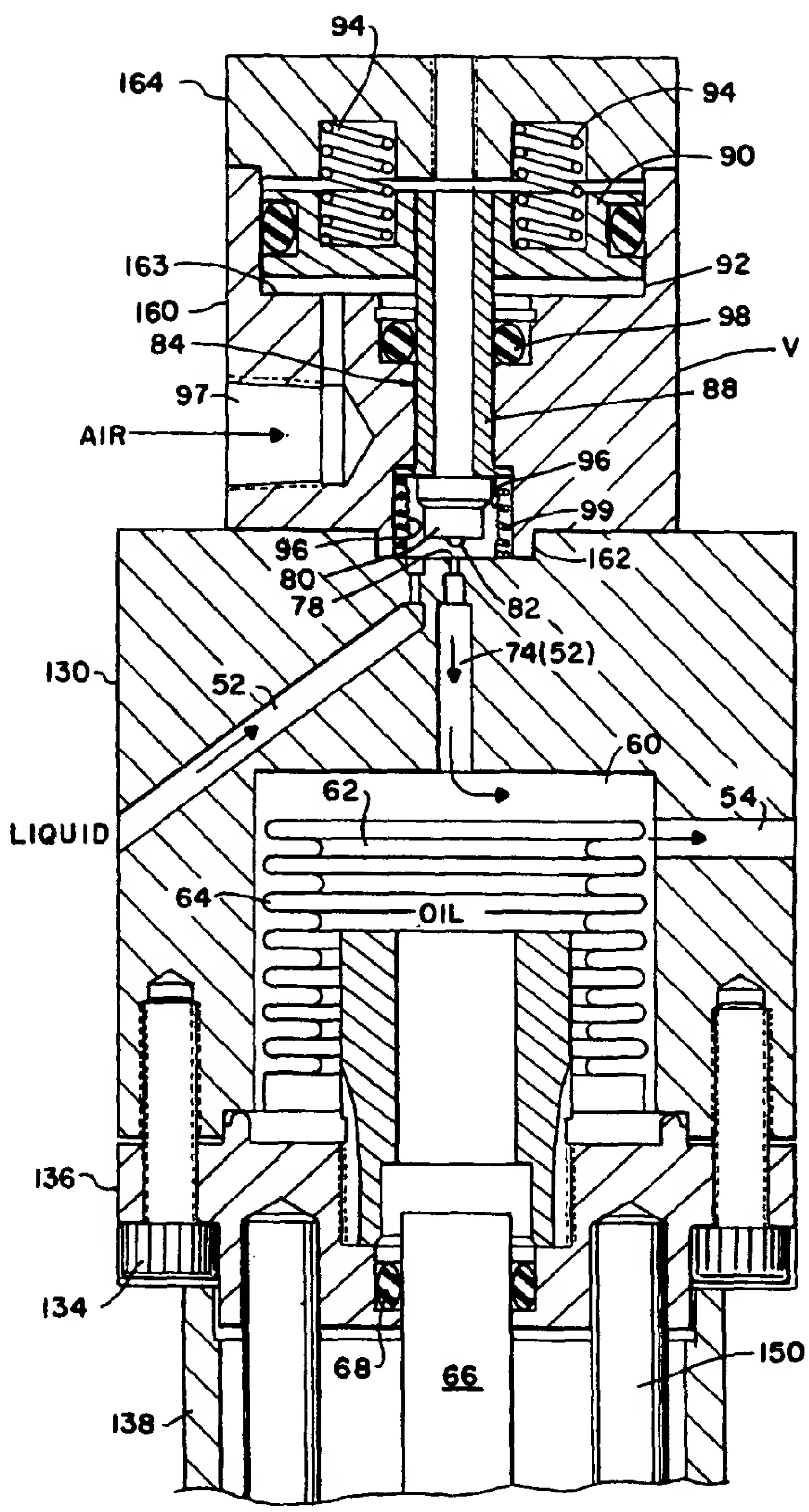
LIQUID
LIQUID
72
74(52)
130b
54
62
60
64
OIL
72
74(52)
130a
54
132
OIL
130c
74
72
132
134
134
136
68
66b
66a
148
138
150
144
144
Px
Px
142
142
146
STEPPING MOTOR 140
STEPPING MOTOR 140

Fig. 5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LIQUID
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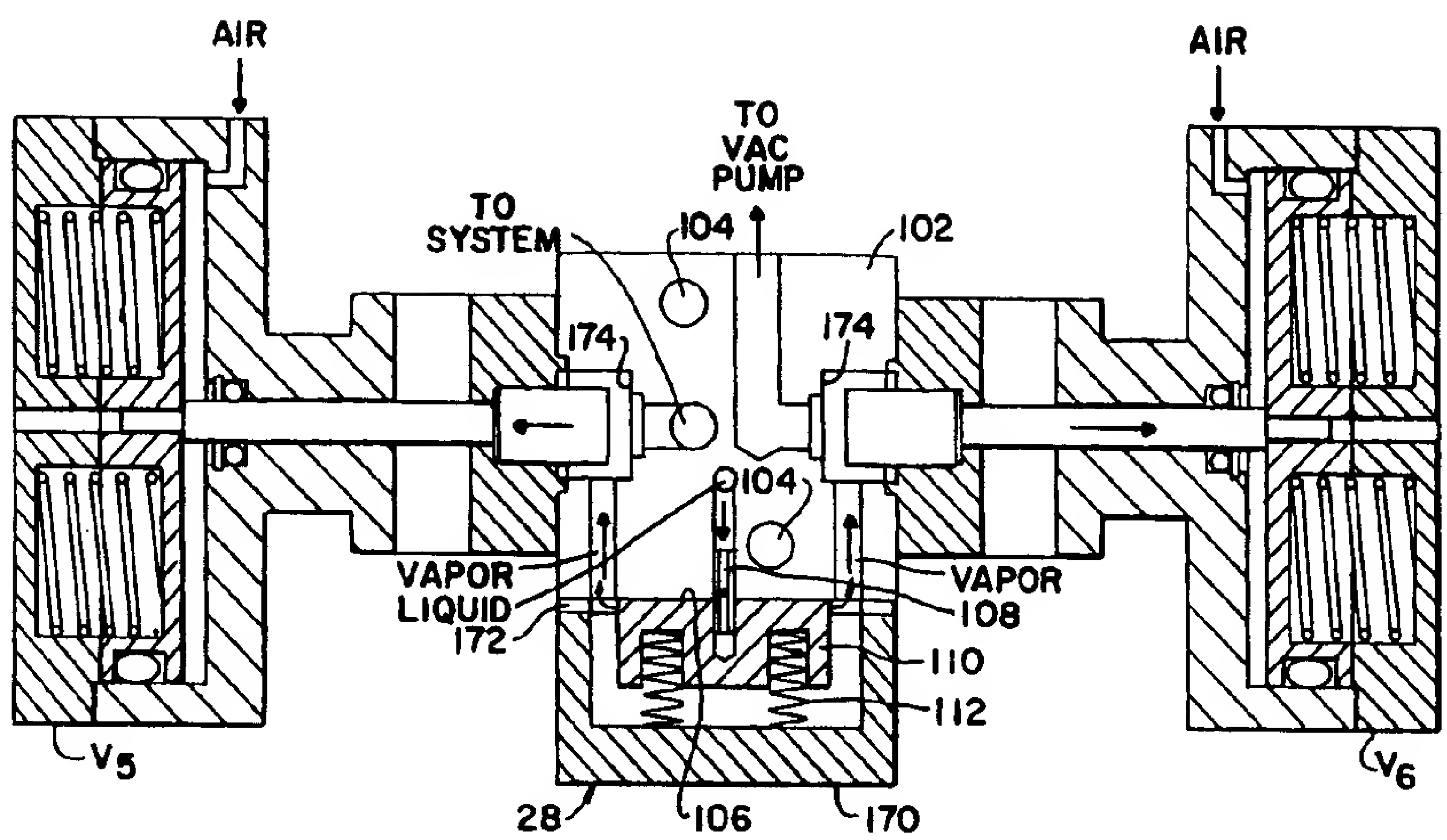
66
138

Fig. 6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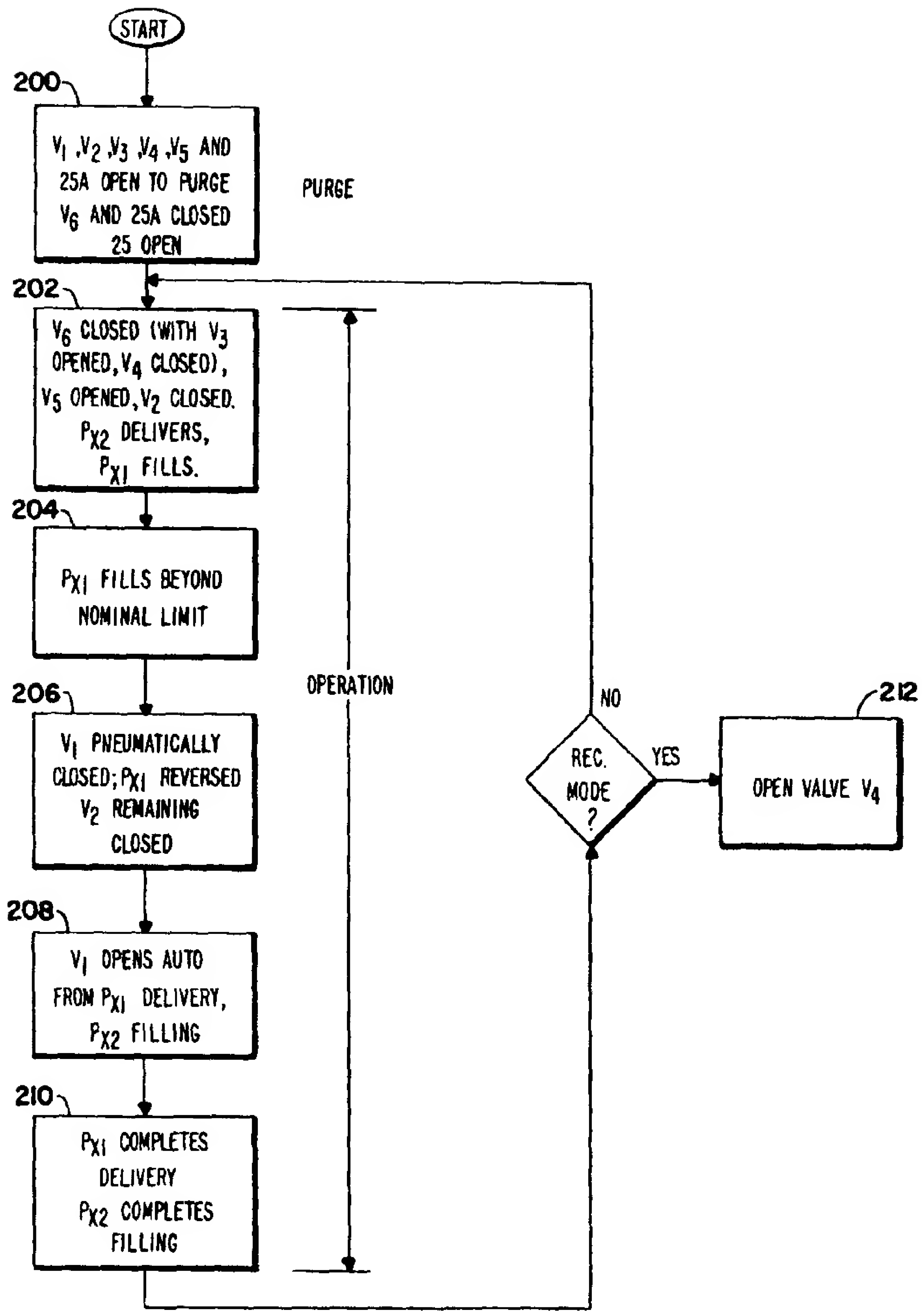
110
112
V5
V6
28
106
170

Fig. 7



START
200
V_1, V_2, V_3, V_4, V_5 AND 25A OPEN TO PURGE V_6 AND 25A CLOSED 25 OPEN
PURGE
202
V_6 CLOSED (WITH V_3 OPENED, V_4 CLOSED), V_5 OPENED, V_2 CLOSED. P_{X2} DELIVERS, P_{X1} FILLS.
204
P_{X1} FILLS BEYOND NOMINAL LIMIT
OPERATION
206
V_1 PNEUMATICALLY CLOSED; P_{X1} REVERSED V_2 REMAINING CLOSED
208
V_1 OPENS AUTO FROM P_{X1} DELIVERY, P_{X2} FILLING
210
P_{X1} COMPLETES DELIVERY P_{X2} COMPLETES FILLING
REC. MODE ?
NO
YES
212
OPEN VALVE V_4

Fig. 8